QUADRUPOLE MASS FILTER WITH FRINGING-FIELD PENETRATING STRUCTURE

BACKGROUND AND SUMMARY OF THE INVENTION

This invention relates to quadrupole mass spectrometers and, more particularly, to the entrance construction of quadrupole mass filters used therein.

The fringing fields near the entrance of a quadrupole mass filter have a serious defocusing effect upon ions approaching and entering the quadrupole. This defocusing effect reduces the ion transmission efficiency and hence the sensitivity of the quadrupole. Accordingly, it is the principal object of this invention to provide a fringing-field penetrating structure for increasing the ion transmission efficiency and hence the sensitivity of the quadrupole.

This object is accomplished in accordance with the illustrated embodiment of this invention by concentrically mounting two conical electrically-conductive tubes about the central axis of the quadrupole with their larger ends lying outside the quadrupole adjacent to an ion source and with their smaller ends lying inside the quadrupole in a region where the defocusing effect of the fringing fields is substantially reduced. The inner tube is operated at a negative DC voltage with respect to quadrupole ground, which is hereinafter defined for purposes of this specification and the claims appended hereto as the mean potential of the primary electrodes. This produces an equipotential region inside the inner tube through which ions from the ion source drift with a higher velocity than they have further inside the quadrupole. The inner tube therefore serves two purposes. First, it injects ions from the ion source into the quadrupole at a point where the defocusing effect of the quadrupolar fringing fields is substantially reduced. Secondly, it shields the ions from the defocusing effects of the quadrupolar fringing fields until they reach the point of injection. The outer tube is operated at quadrupole ground and also serves two purposes. First, it terminates the quadrupolar fields in a desirable manner at the point of ion injection. Secondly, it shields the quadrupole from the perturbing effect of the high negative voltage on the inner tube.

DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic sectional view of a quadrupole mass spectrometer constructed in accordance with the preferred embodiment of this invention.

FIG. 2 is a fragmentary perspective view of the fringing-field penetrating structure at the entrance of the quadrupole mass filter.

FIG. 3 is a stability diagram illustrating the operating characteristics of a quadrupole mass filter.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIGS. 1 and 2, there is shown a quadrupole mass spectrometer including a cylindrical electrically-conductive housing **10** operated at quadrupole ground and having four primary electrodes **12**, **14**, **16** and **18** mounted therein on electrically insulating supports **20**. Housing **10** is positioned within an evacuated enclosure when the quadrupole mass spectrometer is to be employed in the laboratory. However, this evacuated enclosure is unnecessary when the quadrupole mass spectrometer is to be employed for upper atmospheric research in the vacuum of space. Primary electrodes **12**, **14**, **16** and **18** comprise coextensive, electrically-conductive, cylindrical rods extending parallel to one another and symmetrically disposed about a central axis Z. Diametrically opposed rods **12** and **14** have their centers in the X–Z plane and are hereinafter referred to as the X-rods, whereas diametrically opposed rods **16** and **18** have their centers in the Y–Z plane and are hereinafter referred to as the Y-rods. As shown in FIG. 2, X-rods **12** and **14** are electrically connected together and Y-rods **16** and **18** are electrically connected together. An excitation voltage comprising both a balanced AC component V and a balanced DC component ±U is applied between the X-rods and the Y-rods by a drive circuit **22**, all voltages being referred to quadrupole ground. This creates a quadrupole electric field having both AC and DC components between the X-rods and the Y-rods. The positive DC excitation voltage component +U is applied to the X-rods, and the negative DC excitation voltage component −U is applied to the Y-rods.

An ion source is mounted at one end of housing **10** and is symmetrically disposed about the central axis Z. The ion source may comprise, for example, an ionization chamber **24** operated at a positive voltage E_1 of about 5 volts. A filament **26** is mounted adjacent to an aperture **28** in one side of the ionization chamber, and a collector **30** is mounted adjacent to an aperture **32** in the opposite side of the ionization chamber. Positive ions are produced by operating the filament and the collector to provide an electron flow of about 10 milliamperes through a gas sample injected into the ionization chamber by means of a sample inlet (not shown) in one side thereof. A beam of these ions is forced out of the ionization chamber by a pusher electrode **34** operated at a positive voltage E_2 of about 5½ volts.

The ion source further comprises an ion gun having a first electrode **36** operated at the positive voltage E_1 and a second electrode **38** operated at a negative voltage $-E_3$ of about 700 volts. First electrode **36** includes a spherical mesh **40** of radius r_c. This spherical mesh protrudes into the ionization chamber and intersects an imaginary conical surface of revolution generated by rotating a line that intersects the central axis Z at the center of curvature C of mesh **40** about the central axis Z at an angle α of about 20° or less. A circular aperture **42** in second electrode **38** intersects this imaginary conical surface of revolution at a distance r_a of about one-half r_c from the center of curvature C. Electrodes **36** and **38** are shaped to obtain a radial potential distribution between their inner field-forming surfaces. This may be accomplished while providing the electrodes **36** and **38** with a convenient size and shape by the conventional electrolytic tank method. The ion beam forced out of the ionization chamber is focused by the ion gun at a point f on the central axis Z inside the quadrupole where the defocusing effect of the fringing fields is substantially reduced. Focal point f lies on the central axis Z a distance Δ behind the center of curvature C. This distance Δ may be determined with the aid of the graph of FIG. 15.35 on page 461 of Karl R. Spangenberg's book entitled "Vacuum Tubes" and published by McGraw-Hill Book Company, Inc., 1948. For example, Δ equals 1½ inches where the ratio r_c/r_a equals 2.

The defocusing action of the quadrupolar fringing fields upon the beam of positive ions from the ion source can be explained with reference to the stability diagram of FIG. 3, where the abscissa q is proportional to the AC excitation voltage component V and the ordinate a is proportional to the DC excitation voltage component U. In this diagram, the triangularly-shaped region defined by solid lines **44** and **46** represents stable ion motion in both the X and the Y directions. The region to the left of solid line **44** represents unstable ion motion in the Y direction, and the region to the right of solid line **46** represents unstable ion motion in the X direction. If the ratio of the DC excitation voltage component U to the AC excitation voltage component V is held constant, the locus of the operating point of an ion passing through the quadrupole fringing fields is the dashed straight line **48**. The ratio of U to V is adjusted so that this line passes just below the apex of the triangularly-shaped region of stability to maximize the resolution of the quadrupole mass filter. Along dashed line **48** the ion motion is stable everywhere in the X direction and is unstable in the Y direction until nearly the final operating point **50** is reached. This instability in the Y direction reduces the ion transmission efficiency and hence the sensitivity of the quadrupole mass filter.

A fringing-field penetrating structure is provided for injecting the ion beam from the ion source through the fringing fields near the entrance of the quadrupole with a substantially improved efficiency. This structure comprises two concentric,